GENERAL DYNAMICS | CONVAIR

Report No. 8926-160

Material - Titanium - Ti 6Al-4V, Commercially Pure (A-70)

Seam Weld Strengths

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Seam Weld Strengths

Abstract:

Seam welds were made by the electric resistance, roller welding practice in a variety of welding combinations comprised of 0.012" thick rigidized commercially pure, 0.025" thick commercially pure, and 0.025", 0.032" and 0.040" thick Ti 6Al-4V alloys. Tension testing revealed that in all cases, except that one in which 0.040" thick Ti 6Al-4V comprised the thinnest weld joint member, failures occurred in the parent metal; in the exception noted the failure took place in the heat affected zone adjacent to the weld. The efficiency of the weld joints was thus found to be 100 per cent, except in the case of 0.040" thick Ti 6Al-4V where it was found to be 92 per cent.

Reference: Stier, H. H., Turner, H. C., Sutherland, W. M., "Seam Welds with Ti 6Al-4V Titanium Sheet," General Dynamics/Convair Report MP 56-115, San Diego, California, 27 December 1956. (Reference attached).

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
SAN DIEGO

ENGINEERING TEST LABORATORIES

REPORT 56-115
DATE 12-27-56
MODEL F-106A

TITLE

REPORT NO. 56-115
SEAM WELDS WITH Ti-6Al-4V
TITANIUM SHEET

MODEL F-106A

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NO. OF PAGES 13

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REVISIONS

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FORM 1612A-4

REPORT NO. 56-115
SEAM WELDS WITH Ti-6Al-4V
TITANIUM SHEET

OBJECT:

1. To establish satisfactory machine settings for seam welding various combinations of sheets of A-70 and Ti-6Al-4V titanium.

2. To determine the shear strength of various seam-welded comoinations of A-70 and Ti-6Al-4V sheet.

PURPOSE:

To establish procedures, obtain design values and provide data with which military approval may be obtained so that Ti-6Al-4V material may be substituted for A-110-AT material in Convair's planes.

CONCLUSIONS:

The Ti-6Al-4V titanium sheet in the annealed condition is suitable to replace A-110-AT with respect to its seam-welding characteristics; viz.,
(i) the new material can be seam welded with existing Plant II equipment,
(ii) the strength of the welded joints is equal to (or exceeds) that found in A-110-AT.

DESCRIPTION OF SPECIMENS:

Chemical composition and mechanical properties of the titanium sheet used in this test are recorded in Table I.

The following combinations of A-70 and Ti-6Al-4V sheet were seam-welded:

(a) .025 AV to .032 AV
(b) .025 AV to .025 P
(c) .025 AV to .025 AV to .025 AV
(d) .025 AV to .025 AV to .012 R
(e) .025 AV to .012 P to .012 R
(f) .025 AV to .012 R to .012 P
(g) .032 AV to .040 AV to .012 R
(h) .012 R to .025 AV to .012 R
(i) .012 R to .012 R to .025 AV to .032 AV
(k) .025 AV to .025 AV
(l) .032 AV to .032 AV
(m) .040 AV to .040 AV

(Note: In the table above, the number represents thickness of sheet, AV represents Ti-6Al-4V plain sheet, P represents A-70 plain sheet, R represents A-70 rigidized sheet.)

TEST PROCEDURE:

Prior to welding, the titanium panels were prepared as follows:

1. Vapor degrease (solvent 1050-55, MPS 64-03)
2. Alkaline cleaner (Clean 1010-10, MPS 61.01, 150°-180°F.)
3. Hot water
4. Titanium etch (CVAC-ACl, 1010-95, 1.5-3.0%
   CVAC-ACl, 1010-80, 25-35%, MPS 63.03)
5. Cold water
6. Oakite etch (clean 1010-100, MPS 61.03)
7. Hot water
8. Vapor degrease (see step 1.)

Various machine settings on a Precision Seam Welder, 150 KVA, in Plant II were tried until a satisfactory weld was produced; viz., peel tests and microscopic examination revealed

1. Continuous fused zone penetration into the outer sheets of not less than 20% of the original sheet thickness at any point over an area whose major axis is 80% of the interface weld diameter (approximately 50% nugget overlap).

2. No interface nugget expulsion.

3. Freedom from surface burns (straw or blue color at edge of weld acceptable).

Specimens for testing in shear were welded when penetration requirements had been met using a given machine setting.

Tension-shear coupons were mill-cut from seam-welded panels. The panels were welded from two pieces of 3" x 6" material (with the grain direction parallel to the 6-inch length) plus 1" x 6" strips (grain direction parallel to the 6-inch length). (See Figure 1.) In addition, separate panels were welded from rigidized material which had the grain direction of the rigidized sheet perpendicular to the 6-inch length. In this manner the combinations including rigidized A-70 could be tested with the rigidizing parallel to the load (as well as with rigidizing normal to the load).

In this report the side of the rigidized sheet on which the sinusoidal configurations appear as ridges will be called the <u>top</u> surface; the opposite side of the sheet (where the sindusoidal configurations appear as depressions) will be known as the <u>bottom</u> surface of the sheet. (See Figure 2.)

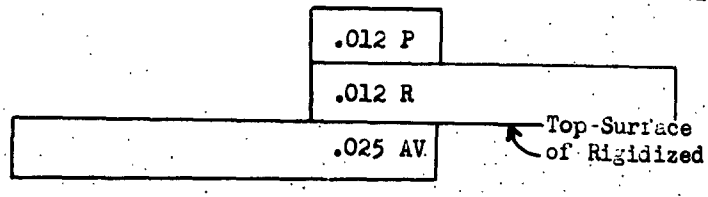
Combinations including rigidized A-70 were placed between the welding electrodes with the rigidized sheet above the plain sheets and, further, with the <u>top</u> surface of the rigidized sheet in contact with the welding electrode. Exceptions to this arrangement were made in the following combinations:

TEST PROCEDURE. (Cont'd.)

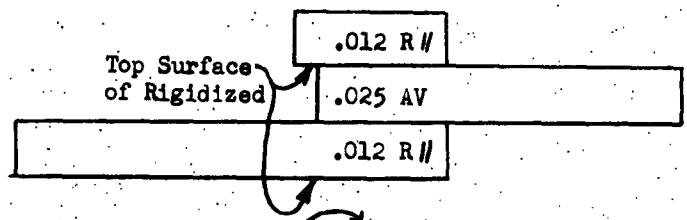
(f) .025 AV to .012 R to .012 P
(h) .012 R to .025 AV to .012 R
(i) .012 R to .012 R to .025 AV to .032 AV

The orientation of sheets in these combinations is shown in cross section:

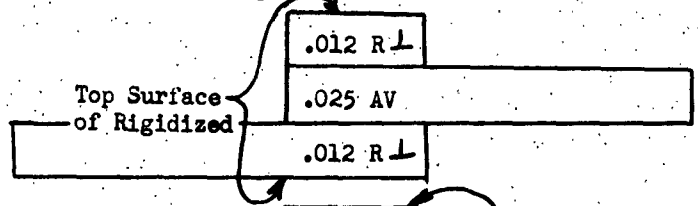
(f) - I & II



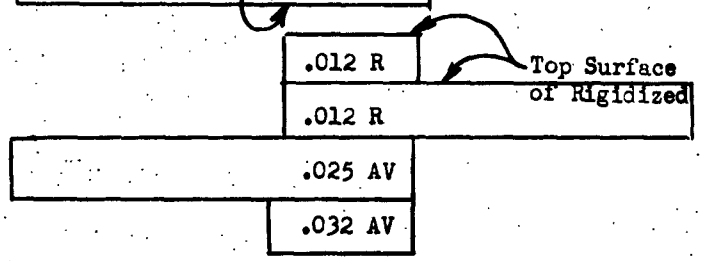
(h)- I



(h) - II



(i) - I & II



(Note: .012 R // has the rigidizing parallel to the load and
.012 R ⊥ has the rigidizing perpendicular to the load.)

TEST PROCEDURE. (Cont'd.)

Shear specimens were pulled in a Tinius Olsen tensile machine at a crosshead speed of 0.2 in. per min. until failure.

DISCUSSION OF PROCEDURE:

Future tests of this nature should employ 4" x 8" instead of 3" x 6" material. This will permit gripping shear coupons securely in the tensile machine and, further, enough material will be available for 5 coupons per panel.

Sheet combinations which included rigidized A-70 were tack-welded at 3 points along the overlap. This was necessary to prevent arcing. The tacks were so placed and the seam so welded that the seam covered up the tacks. The tack-welds had no observable affect on weld strength except in one specimen where the tack lay outside the seam weld, in which case the weld strength was greatly reduced.

RESULTS AND DISCUSSION:

Seam-weld machine settings and corresponding tension-shear values are given in Table II and III.

Failures in the parent metal during testing indicates a weld-joint efficiency of 100%, that is, the weld is as strong as the parent metal.

The efficiency of all welds using rigidized A-70 material may be assumed to be 100% since the few random failures in the heat-affected zone (HAZ) showed strengths equal to that of the parent metal.

Welds with .025 AV, .025 P, and .032 AV showed 100% efficiency with all failures occurring in parent metal.

The welded combination of .040 AV to .040 AV showed 92% efficiency with all failures occurring in the heat-affected zone.

A comparison between physical properties of parent metal and breaking strength of seam-welded metal is given for 6Al-4V and A-70:

Material	Ult. Strength (Parent)	Ult. Strength (Weld)	Efficiency
.012 R	(not tested)	87,000 psi (ave.)	100%
.025 P	100,400 psi (ave.)	105,100 psi (ave.)	100%
.025 AV	134,900 psi (ave.)	138,000 psi (ave.)	100%
.032 AV	137,100 psi (ave.)	136,300 psi (ave.)	100%
.040 AV	141,700 psi (ave.)	130,700 psi (ave.)	92%

A similar comparison of values for A-110-AT taken from report 9354 is given:

Gauge	Ult. Strength (Parent)	Ult. Strength (Weld)	Efficiency
.032	127,000 psi (ave.)	130,000 psi (ave.)	100%

RESULTS AND DISCUSSION, (Cont'd.)

Microscopic examination of all welds showed sound nuggets and penetration from 60% to 90% into the outer sheets. The combination of .025 F to .025 AV showed a coarse mixture of the respective microstructures at the interface within the nugget area.

Values for shear test no's. (e) - I - 2, (h) - I - 2, and (k) - 4 were omitted from the Table III for the following reason:

e-I-2, the tensile machine operator damaged the specimen when clamping specimen into the grips of the tensile machine.
h-I-2, a tack weld lay outside the seam weld and acted as a local stress-raiser.
k-4, the specimen failed in the metal held within the jaw of the testing machine.

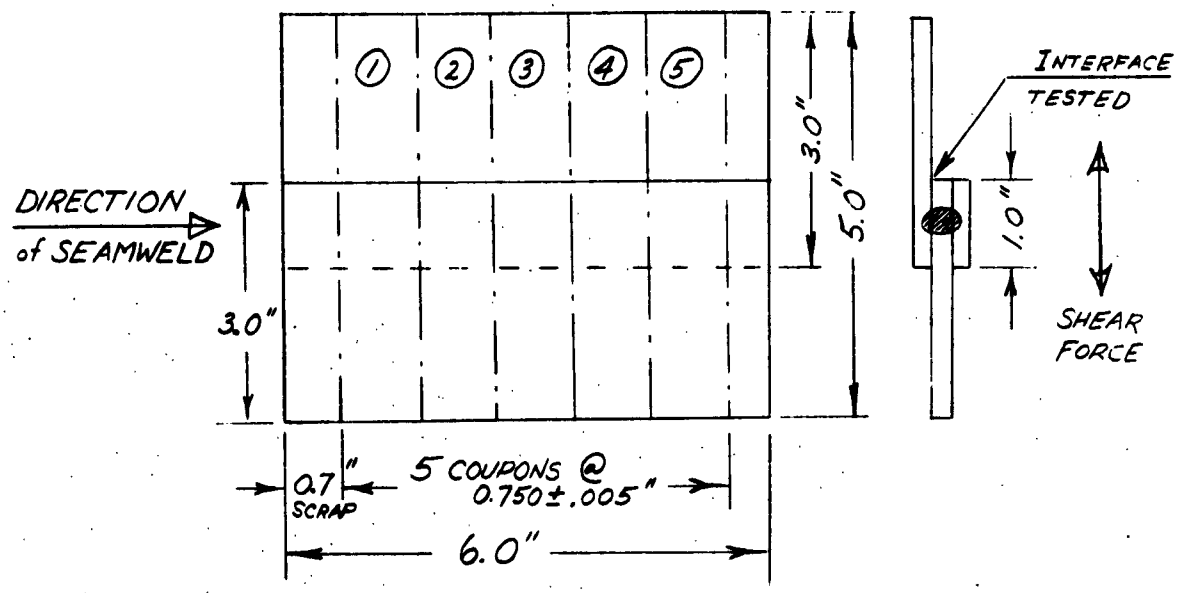


FIGURE 1 (a) Diagram of welded panel showing how 5 coupons were mill-cut from each panel.

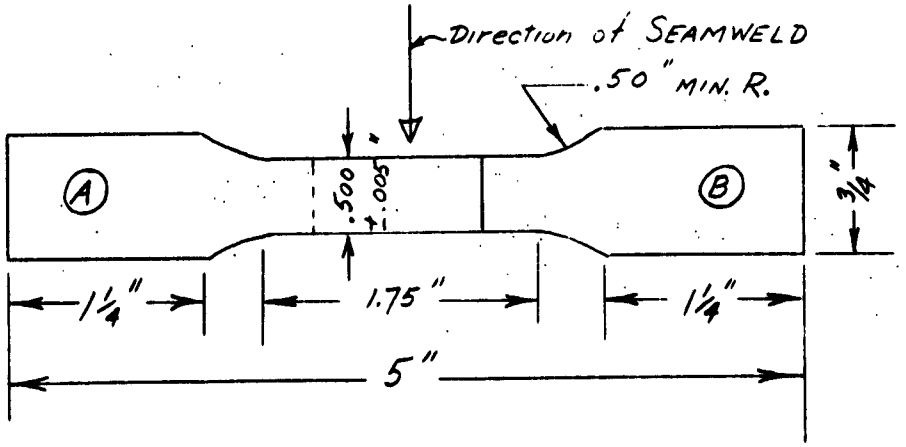


FIGURE 1 (b) Diagram of individual shear coupons cut from panels made from .012 R where A = .025 AV or .040 AV or .012 P and where B = .012 R.

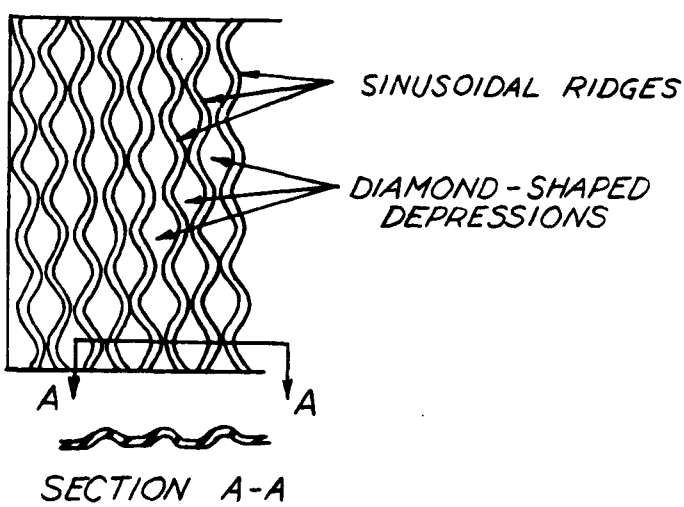


FIGURE 2 - TOP VIEW OF RIGIDIZED SHEET

NOTE: In this report the side of the rigidized sheet on which the sinusoidal configurations appear as ridges is called the top surface.

FORM 73 CONVAIR SAN DIEGO

TABLE I. MECHANICAL PROPERTIES & CHEMICAL COMPOSITION OF SPOTWELDED MATERIALS

MATERIAL	MANUF.	GAUGE (NOMINAL) INCH	TYPE OF SHEET	SOURCE OF DATA AND PROPERTIES	YIELD STRENGTH LONGITUDINAL PSI	YIELD STRENGTH TRANSVERSE PSI	TENSILE STRENGTH LONGITUDINAL PSI	TENSILE STRENGTH TRANSVERSE PSI	ELONG. IN 2" %	CHEMICAL COMPOSITION IN PERCENT (%) VENDOR) C	N_2	H_2	Fe	Al	V	HEAT NO.
Ti-6Al-4V	T.M.C.A.	.025	PLAIN	ETL	98,000	108,000	137,000	134,900	9.5 L / 10.5 T	.01	.009	.008	.13	6.1	4.0	M-3803
				% TMCA	122,820	139,700	136,520	140,000	7.0 L / 7.0 T							
Ti-6Al-4V	T.M.C.A.	.032	PLAIN	ETL	—	129,000	—	137,100	12.0 T	.010	.009	.012	.12	6.2	4.1	M-3890
				% TMCA	139,800	139,800	143,800	142,000	9.0 L / 11.0 T							
Ti-6Al-4V	T.M.C.A.	.040	PLAIN	ETL	—	131,700	—	141,700	12.5 T	.012	.013	.015	.14	6.4	4.1	M-3804
				% TMCA	137,100	139,680	142,310	141,270	13.0 L / 12.0 T							
RC-70	Rem Cru	.012	ROLLED	ETL	← NOT TESTED →					← NOT AVAIL. →			—	—	T-43020	
				% R.C.	← NOT AVAIL. from Purch. →											
MST III	Mallory-Sharon	.012	PLAIN	ETL	—	72,400	—	88,000	26.5 T	.05	.023	.0084	.26	—	—	25179
				% M.S.	73,600	76,200 ± 5000	94,200	91,500 ± 5000	22.1 ± 2.3							
Ti-75-A	T.M.C.A.	.025	PLAIN	ETL	—	76,500	—	100,400	26.5 T	.02	.008	.006	.07	—	—	M-3748
				% TMCA	74,700	83,300	96,800	97,400	25.5 L / 25.5 T							
				MDR	75,400	-	99,300	-	24.5 L							

NOTE: Convair's ENG. TEST LAB. (ETL) made independent tensile tests of 2 specimens cut from each sheet material & thickness used, except the rigidized material, to obtain yield, ultimate & elongation (strain rate = .003 in/in/min).

T.M.C.A. = TITANIUM METALS CORP. OF AMERICA
R.C. = REM-CRU TITANIUM
M.S. = MALLORY-SHARON
MDR = CONVAIR "Material Data Report"
ETL = CONVAIR'S ENGINEERING TEST LAB.

NOTE: UNDER "ELONG IN 2": L = Longitudinal
T = Transverse

FORM 73 CONVAIR SAN DIEGO

TABLE II. MACHINE SETTINGS FOR WELDING Ti-6Al-4V ON PRECISION SEAM WELDER (MACH. #1, PLANT II) SERIAL No. 251648

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)-I	(j)-II	(k)	(l)	(m)
Gauge & Mat'l. welded	.025AV .032AV	.025AV .025P	.025AV .025AV .025AV	.012R .025AV .025AV	.012R .012P .025AV	.012P .012R .025AV	.012R .040AV .032AV	.012R .025AV .012R	.012RII .012RII .025AV .032AV	.032RL .032RL .025AV .032AV	.025AV	.032AV .032AV	.040AV .040AV
Throat Depth	←					3 9/16 in.							→
Dist. between Arms	←					6 1/2 in.							→
Heat Range %	55	59	56	57	67	51.5	69	59	65	67	62	43	56
Weld Time, cycles	1p 2lf	1p 2lf	2p 1lf	2p 1lf	1p 1lf	2p 1lf	2p 1lf	2p 2lf	2p 1lf	2p 1lf	1p 2lf	2p 2lf	2p 2lf
Cool Time, cycles	10	10	8	8	7	7	N	N	9	9	10	10	12
Firing Pattern	←				NORMAL ½ CYC. ALT.								→
Mode Selector	←				SEAM - DIRECT								→
Pressure, Up	13	13	11	11	11	11	20	11	15	19	13	13	13
" , Down	8	7½	6	6	6	6	14	5½	10	14	8	7½	7½
Spring Deflector	10	10	10	10	10	10	17	8	15	16	10	10	10
Speed Control	3.3	3.3	4	4	4	4	3	3.6	3	3	3.3	3.0	3.0
Transform. Tap Setting	←				SERIES								→
SPT	18	18	20	18	25	21	19	17	22	22	18	17	15
Continuous	←				YES								→

ELECTRODES USED FOR ALL WELDS

Top – Class III, 12" Diam., 3" Contour Radius

Bottom – Class III, 10" Diam., 3" Contour Radius

KEY:

AV = Ti-6Al-4V plain sheet
.012 P = MST III plain sheet, .012" gauge
.025 P = Ti-75-A plain sheet .025" gauge
.012 R = RC-70 rigidized sheet, .012" gauge

R II = rigidized material having grain direction parallel to pull direction
R ⊥ = " " " " " perpendicular " "

UNDER "Weld Time"

p = pulse cycles
lf = low frequency cycles

CONVAIR SAN DIEGO
FORM 73

TABLE III. RESULTS OF TENSION SHEAR TESTS ON SEAM-WELDED Ti-6Al-4V SPECIMENS

Identif.	Gauge & Mat'l welded Ⓐ	Ⓑ	Ⓒ	Interface Tested	Thickness of Failed Sheet	Area (in²)	Load at Failure (pounds)	WELD Ultimate Strength (psi)	WELD Ave. Ultimate Strength (psi)	Location of Failure
(a) - 1	.025AV	.032AV		Ⓐ-Ⓑ	Ⓐ = .024"	.0180	2550	141,600		Parent of .025AV
- 2	"	"		"	"	"	2515	139,500		"
- 3	"	"		"	"	"	2580	143,300	141,100	"
- 4	"	"		"	"	"	2580	143,300		"
- 5	"	"		"	"	"	2535	140,800		"
(b) - 1	Ⓐ .025AV	Ⓑ .025P		Ⓐ-Ⓒ	Ⓐ = .025"	.01875	1985	105,800		Parent of .025P
- 2	"	"		"	"	"	1960	104,600		"
- 3	"	"		"	"	"	1955	104,200	105,100	"
- 4	"	"		"	"	"	1990	106,100		"
- 5	"	"		"	"	"	1965	104,700		"
(c) - 1	Ⓐ .025AV	Ⓑ .025AV	Ⓒ .025AV	Ⓐ-Ⓒ	Ⓐ = .0255"	.01277	1790	140,300		Parent of .025AV
- 2	"	"	"	"	Ⓐ = .025"	.01248	1725	138,200	140,700	"
- 3	"	"	"	"	Ⓐ = .025"	"	1760	141,000		"
- 4	"	"	"	"	Ⓐ = .025"	"	1790	143,300		"
(d)-I - 1	Ⓐ .012R//	Ⓑ .025AV	Ⓒ .025AV	Ⓐ-Ⓒ	Ⓐ = .0115"	.00580	505	87,200		Parent of .012R
- 2	"	"	"	"	"	.00579	500	86,400	86,800	"
- 3	"	"	"	"	"	.00576	500	86,900		"
- 4	"	"	"	"	"	.00578	500	86,600		HAZ of .012R
(d)-II - 1	.012R⊥	"	"	"	"	.00560	507	90,500		Parent of .012R
- 2	"	"	"	"	"	.00573	516	90,000	89,400	"
- 3	"	"	"	"	"	.00571	501	87,700		"
- 4	"	"	"	"	"	.005866	525	89,500		"

KEY:

.012R// = rigidized sheet of RC-70 with grain direction parallel to PULL direction.

.012R⊥ = rigidized sheet of RC-70 with grain direction perpendicular to PULL direction

AV = Ti-6Al-4V plain

.025P = Ti-75-A plain

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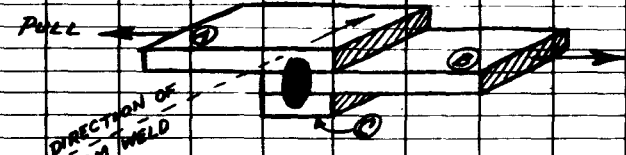
TABLE III. (CON'T.)

Identif.	Gauge & Mat'l. welded Ⓐ	Ⓑ	Ⓒ	Interface Tested	Thickness of Failed Sheet	Area (in²)	Load at Failure (pounds)	Ultimate Strength (psi)	Ave. Ultimate Strength (psi)	Location of Failure
(e)-I-1	.012R ∥	.012P	.025AV	Ⓐ-Ⓑ	Ⓐ = .0115"	.00581	505	86,900		Parent of .012R
-2	"	"	"	"	"	.00580	460	79,400	83,200	"
-3	"	"	"	"	"	.00581	525	90,400		"
-4	"	"	"	"	"	.00582	510	87,700		"
(e)-II-1	.012R⊥	"	"	"	"	.00578	470	82,000		Parent of .012R
-2	"	"	"	"	"	.00578	460	80,300	79,400	"
-3	"	"	"	"	"	.00578	430	75,000		" & HAZ of .012R
-4	"	"	"	"	"	.00573	460	80,300		Parent of .012R
	Ⓐ	Ⓑ	Ⓒ							
(f)-I-1	.025AV	.012R ∥	.012P	Ⓐ-Ⓐ	Ⓑ = .0115"	.00576	505	87,700		Parent of .012R
-2	"	"	"	"	"	.00574	505	88,000	87,500	"
-3	"	"	"	"	"	.00577	505	87,600		"
-4	"	"	"	"	"	.00578	500	86,500		"
(f)-II-1	"	.012R⊥	"	"	"	.00569	475	83,400		"
-2	"	"	"	"	"	.00569	485	85,200	83,200	"
-3	"	"	"	"	"	.00567	475	83,800		"
-4	"	"	"	"	"	.00570	460	80,700		"
	Ⓐ	Ⓑ	Ⓒ							
(g)-I-1	.012R ∥	.040AV	.032AV	Ⓐ-Ⓐ	Ⓓ = .0115"	.00562	505	89,800		Parent of .012R
-2	"	"	"	"	"	.00563	515	91,400	89,800	"
-3	"	"	"	"	"	.00560	525	93,700		"
-4	"	"	"	"	"	.00564	475	84,200		HAZ of .012R
(g)-II-1	.012R⊥	"	"	"	"	.00579	495	85,500		"
-2	"	"	"	"	"	.00578	525	90,800	89,200	Parent of .012R
-3	"	"	"	"	"	.00577	500	86,600		HAZ of .012R
-4	"	"	"	"	"	.00579	520	89,800		Parent of .012R



KEY:

.012 R ∥ = rigidized sheet of RC-70 with grain direction parallel to PULL direction

.012 R ⊥ = rigidized sheet of RC-70 with grain direction perpendicular to PULL direction

.012 P = MST III plain

AV = Ti-6Al-4V plain

FORM 75 CONVAIR SAN DIEGO

TABLE III. (CON'T.)

Identif.	Gauge & Mat'l. welded Ⓐ	Ⓑ	Ⓒ	Ⓓ	Interface Tested	Thickness of Failing Sheet	Area (in.²)	Load at Failure (pounds)	Ultimate Strength (psi)	Ave. Ultimate Strength (psi)	Location of Failure
(h)-I-1	.012RII	.025AV	.012RII		Ⓑ-Ⓒ	Ⓒ = .0115"	.00587	500	85,200		HAZ of .012R
-2	"	"	"		"	"	.00593	403	67,900	84,700	" & Parent of .012R
-3	"	"	"		"	"	.00591	475	80,400		HAZ of .012R
-4	"	"	"		"	"	.00594	525	88,400		"
(h)-II-1	.012RL	"	.012RL		"	"	.005915	550	93,000		"
-2	"	"	"		"	"	.00590	545	92,400	91,900	Parent of .012R
-3	"	"	"		"	"	.005925	536	90,500		"
-4	"	"	"		"	"	.005925	535	90,300		"
-5	"	"	"		"	"	.00593	535	90,200		HAZ of .012R
	Ⓐ	Ⓑ	Ⓒ	Ⓓ							
(i)-I-1	.012RII	.012RII	.025AV	.032AV	Ⓑ-Ⓒ	Ⓒ = .0115"	.00581	524	89,200		Parent of .012R
-2	"	"	"	"	"	"	"	512	87,200		"
-3	"	"	"	"	"	"	"	511	86,800	87,100	"
-4	"	"	"	"	"	"	"	489	85,100		"
-5	"	"	"	"	"	"	"	505	87,400		"
(i)-II-1	.012RL	.012RL	"	"	"	"	.005965	550	92,200		"
-2	"	"	"	"	"	"	.00594	530	89,200	88,300	"
-3	"	"	"	"	"	"	.00584	480	82,200		"
-4	"	"	"	"	"	"	.00604	540	89,400		"

KEY:

.012 R II = rigidized sheet of RC-70 with grain direction parallel to PULL direction

.012 R L = rigidized sheet of RC-70 with grain direction perpendicular to PULL direction

AV = Ti-6Al-4V plain

CONVAIR
SAN DIEGO
FORM 73

TABLE III. (CON'T.)

Identif.	Gauge & Mat'l. welded Ⓐ	Gauge & Mat'l. welded Ⓑ	Interface Tested	Thickness of Failed Sheet	Thickness of Sheet	Area (in.²)	Load of Failure (pounds)	Ultimate Strength (psi)	Ave. Ultimate Strength (psi)	Location of Failure
(A) - 1	.025AN	.025AN	Ⓐ-Ⓑ		.026"	.0195	2640	135,400		Parent
- 2	"	"	"		"	"	2675	137,200		"
- 3	"	"	"		"	"	2645	135,500	136,000	"
- 4	"	"	"		"	"	1940 ✓	X		Jaw-Gripped Metal
- 5	"	"	"		"	"	2650	136,000		Parent
(L) - 1	.032AN	.032AN	"		.036"	.0270	3670	136,000		Parent
- 2	"	"	"		"	"	3690	136,700		"
- 3	"	"	"		"	"	3625	134,200	136,300	"
- 4	"	"	"		"	"	3710	137,500		"
- 5	"	"	"		"	"	3700	137,000		"
(m) - 1	.040AN	.040AN	"		.050"	.0375	4900	130,600		HAZ
- 2	"	"	"		"	"	4915	131,000		"
- 3	"	"	"		"	"	4900	130,500	130,700	"
- 4	"	"	"		"	"	4920	131,200		"
- 5	"	"	"		"	"	4890	130,500		"